ENGINEERING CASE LIBRARY

ECL 230

DIESEL TO DETRITUS (A)

"We have a diesel engine which just knocked itself apart with only 110 hours of operation. Can you come look at it and tell us what went wrong?" -- This was a phone call from an attorney representing a construction company.

The Circumstances

A building contractor had an electrical generator on a construction site to provide electrical energy under emergency conditions involving loss of power from the normal supply. This generator was powered by a six-cylinder diesel engine rated at 384-brake horsepower.

Operating instructions for the engine indicated that if the engine were used as a standby, (as was the case with this engine) it should be started and run for about an hour at least once a week. The contractor had put the diesel engine in service one April. In keeping with the instructions, the engine was operated on a weekly basis. Twenty months later, after about 110 hours of operation as recorded by a clock on the engine, the engine failed.

Observations

Failure was rather spectacular with several components damaged including the cylinder block with a hole knocked through the crankcase wall.

The counterweight, after removal from the engine, is shown in Figure 1. This counterweight was lodged between the connecting rod and the cylinder block.

The connecting rod from No. 6 cylinder is in Figure 2. A definite bend is obvious in the originally straight rod, forged in an H section from alloy steel.

The push rods from No. 6 cylinder are seen in Figure 3. Both rods are obviously bent with one more so than the other.

The underside of the head from No. 6 cylinder is shown in Figure 4. The exhaust valve is in place while the inlet valve has been removed. There are two places on the edge of the inlet valve seat which appear to be gouges. There are a number of markings on the surface of the head but there is little, if any, indentation of the surface. The removable cylinder liners were cast iron with chromium plating in the bore.

The top of the piston from No. 6 cylinder is seen in Figure 5. The "square" dark markings on the top are actually indentations in the piston which was made of a low expansion aluminum alloy. The supports on the underside of the piston for the wrist pin were broken off. There was also a crack across the bottom of the piston.

Two inlet valves are shown in Figure 6. The one on the left is from No. 5 cylinder and shows no evidence of damage. The valve on the right is from No. 6 cylinder. It is obvious that two segments are missing from the deflector. Definite chevron markings were obvious to the eye.

The top surface of No. 6 inlet valve diametrically opposite the deflector is seen in Figure 7. In addition to the portions missing from the edge, there are two small indentations. Some portions are missing along the edge in the same location on the bottom side of the valve.

Each inlet valve has two springs. The outer spring has a free length of 0.0983 m (3.870 in), an inner diameter of 0.0342 m (1.348 in) and a spring rate of 15600 N/m (89 lb/in). The inner spring has a free length of 0.0892 m (3.510 in), an outer diameter of 0.0342 m (1.348 in), and a spring rate of 6500 N/m (37 lb/in). The service manual for this engine recommended a new set of valve springs after 6667 hr at 1800 rpm. The maker of a similar engine had provided valve springs which were essentially the same except the outer diameter of the inner spring was 0.0320 m (1.261 in). This second maker recommended a new set of springs after 12000 hr of service.

Figure 8 shows the outer spring from No. 5 cylinder with five segments of the outer spring from No. 6 cylinder. It is not certain that these were the only segments from this spring. The fracture ends of each of these five segments were carefully examined under a binocular microscope.

Figures 9 and 10 show the fracture surface of one segment of No. 6 outer spring, the one indicated by the piece of tape around a segment in Fig. 8.

One doesn't expect a diesel engine to fail in 110 hours of operation, let alone in such a spectacular fashion. What went wrong? What can be done about it to prevent future failures?

Fig. 1: Counterweight showing gouges and generally damaged condition after removal from the engine. Approx. ½X

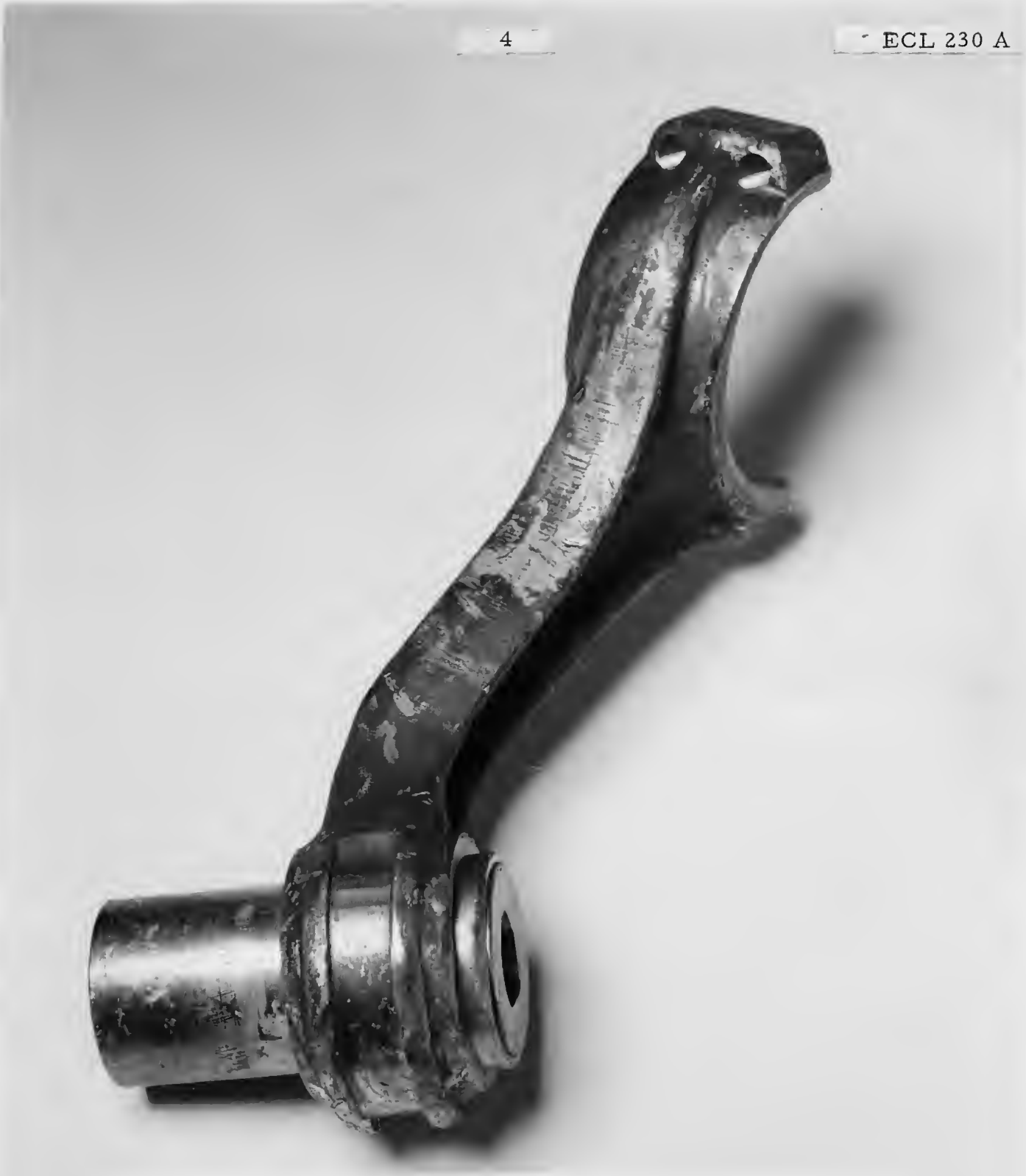

Fig. 2: Connecting rod and wrist pin from No. 6 cylinder. Note the appreciable bend.
Approx. ½X

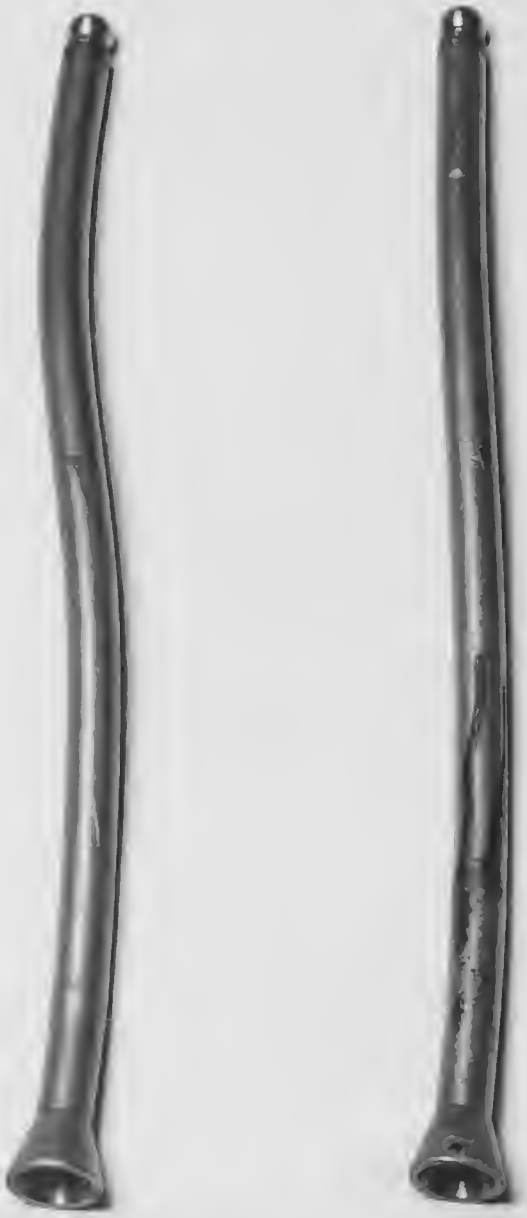

Fig. 3: Push rods from No. 6 cylinder. Approx. ½X

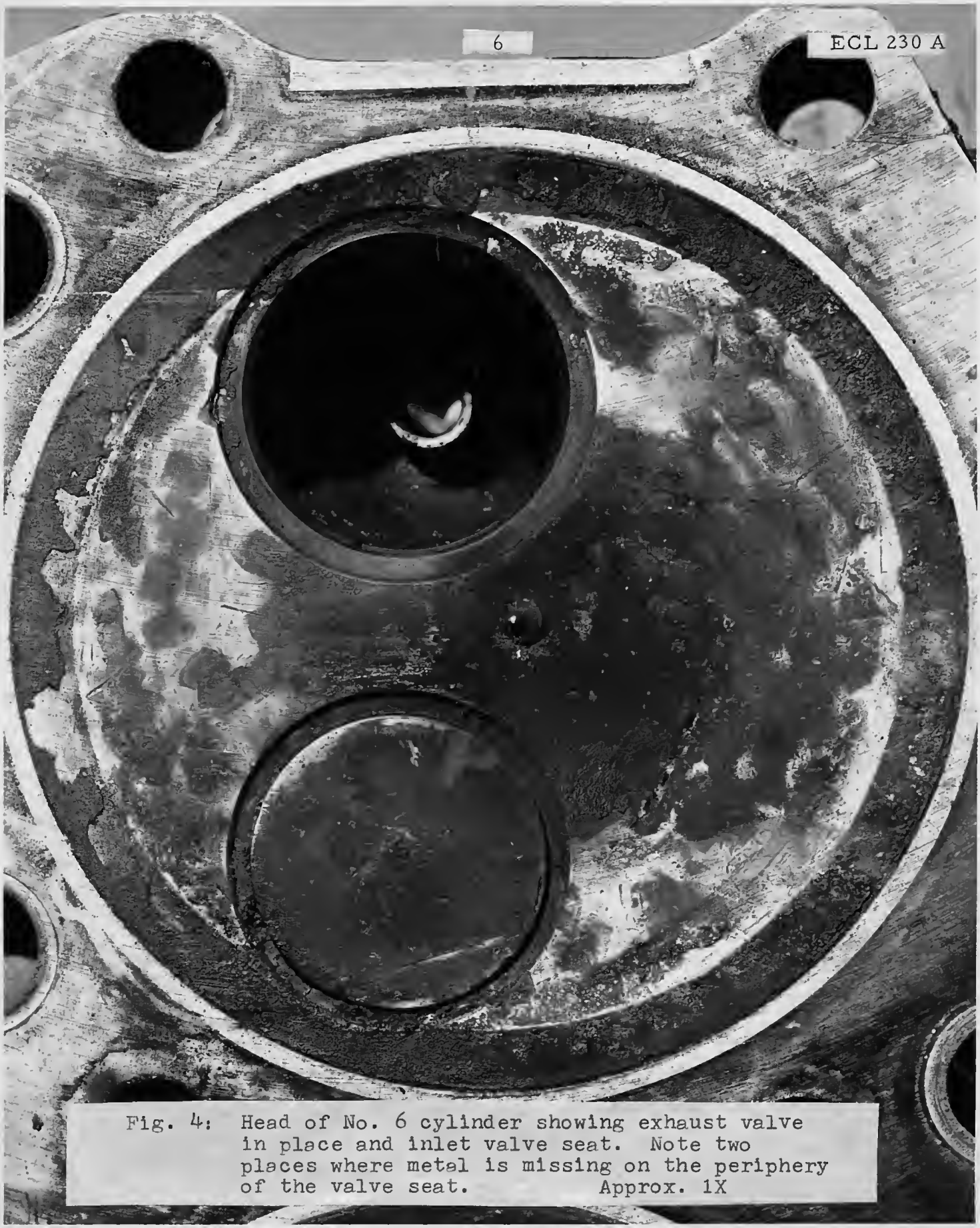

Fig. 4: Head of No. 6 cylinder showing exhaust valve in place and inlet valve seat. Note two places where metal is missing on the periphery of the valve seat. Approx. 1X

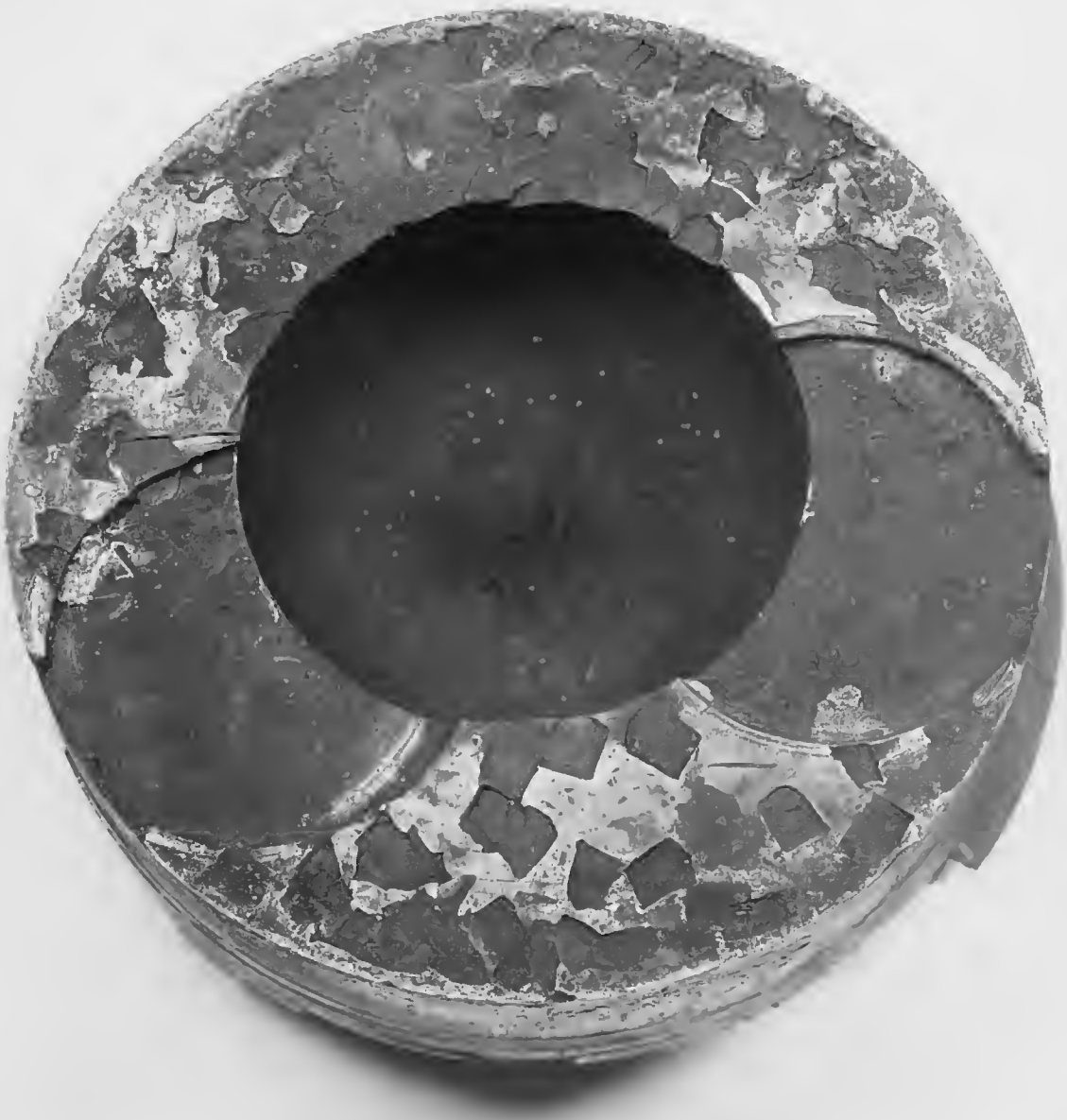

Fig. 5: Top of piston from No. 6 cylinder. The "square" dark areas are actually indentations in the aluminum piston. Approx. 1X

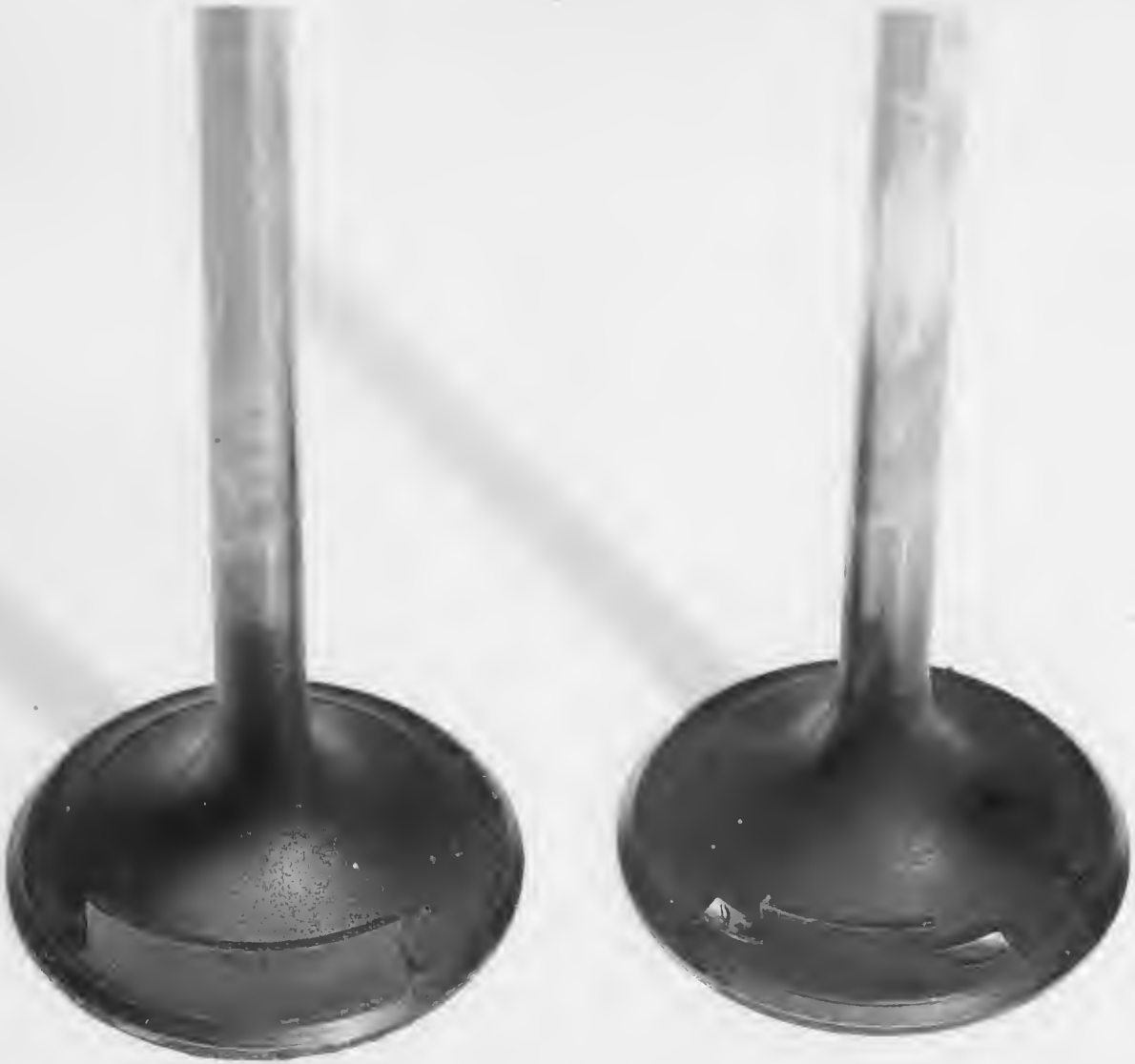

Fig. 6: Inlet valves -- from No. 5 cylinder on the left, from No. 6 cylinder on the right. Note two sections are missing from the deflector on the valve from No. 6 cylinder. Approx. 1X

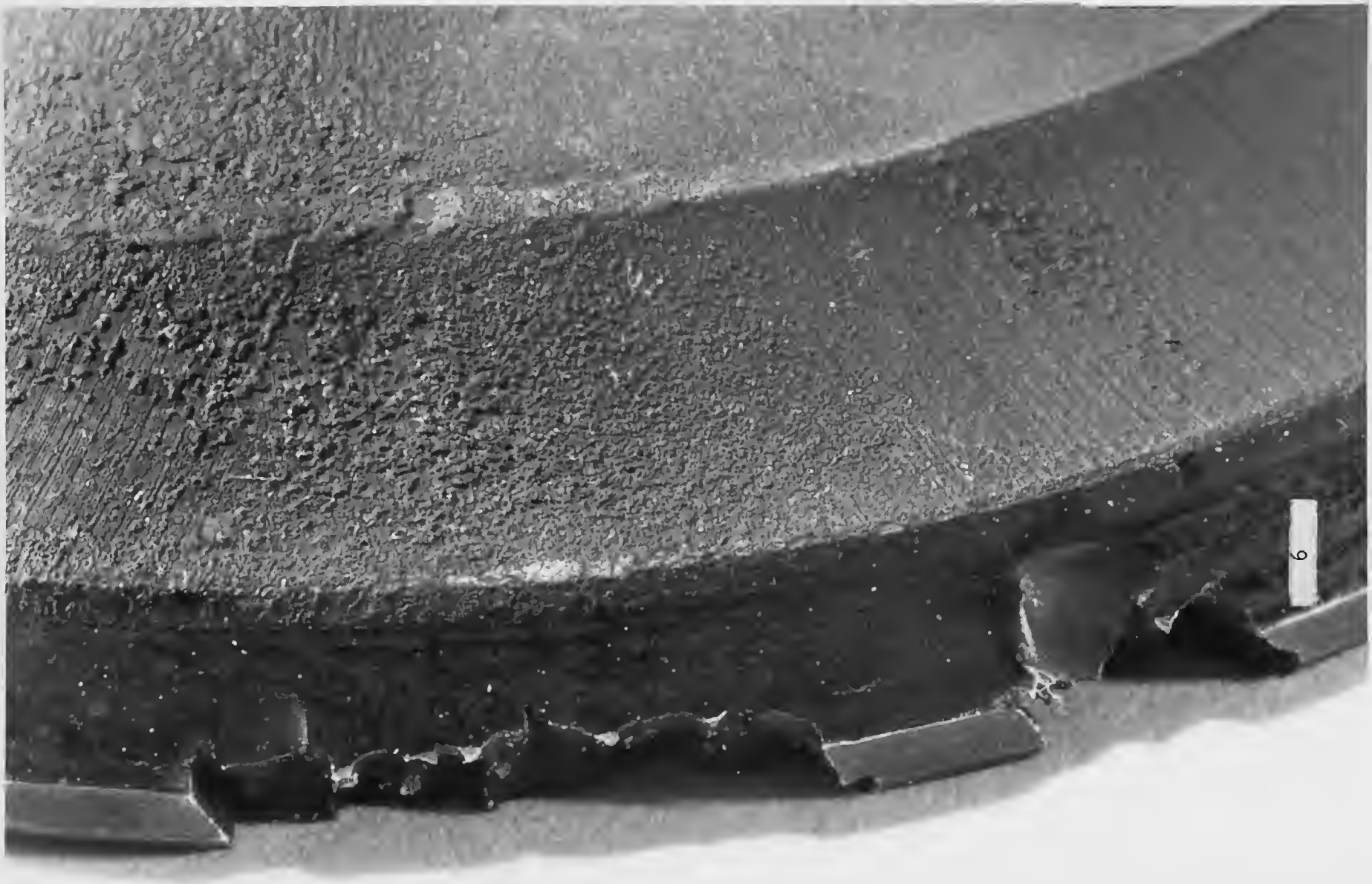

Fig. 7: Top side of inlet valve from No. 6 cylinder located diametrically opposite from the deflector. Approx. 10X

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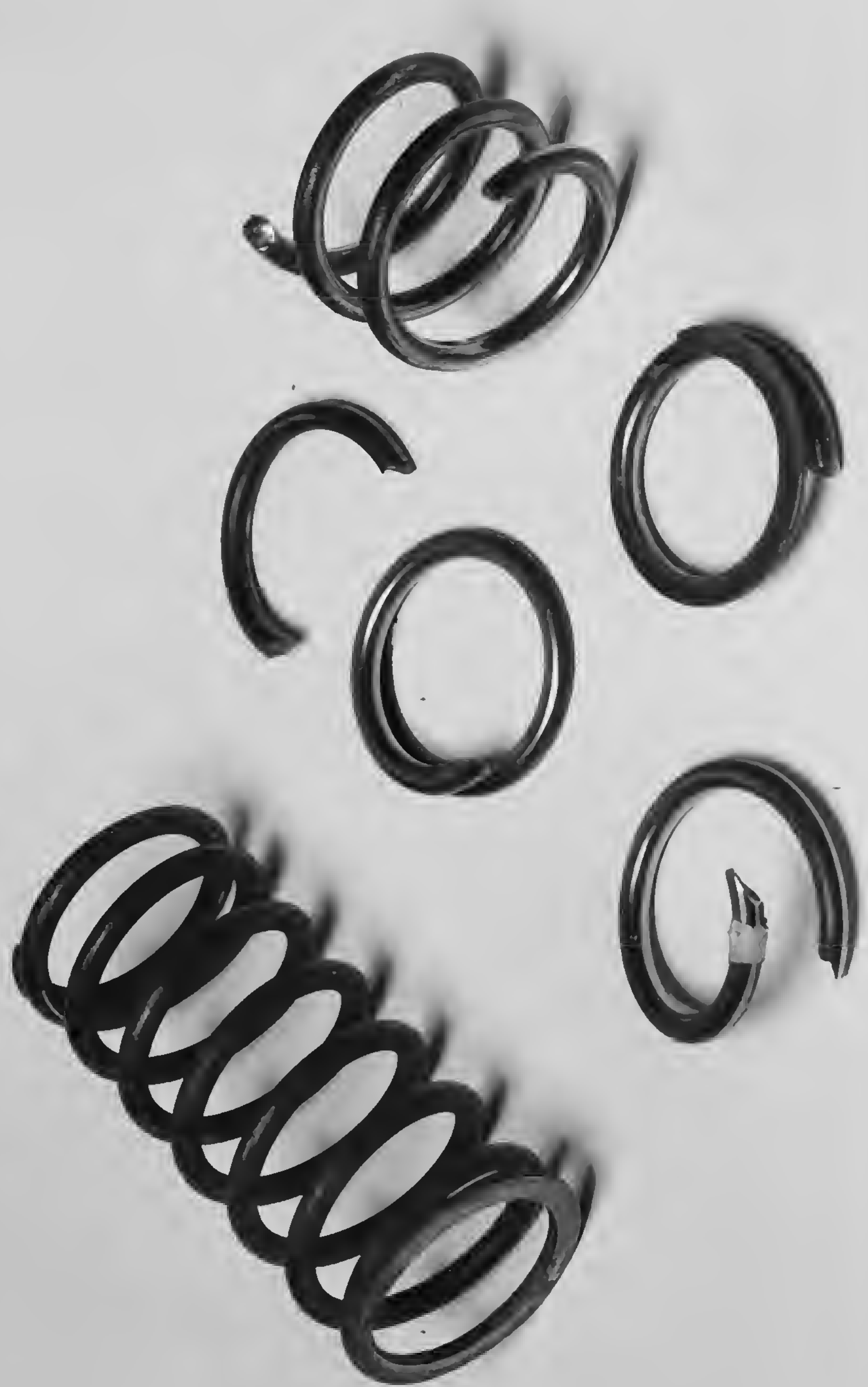

Fig. 8: Outer springs from inlet valves -- The complete spring is from No. 5 cylinder. The five segments shown are from No. 6 cylinder. Approx. 3/4 X

Fig. 9: Fracture surface of one segment of the outer spring from No. 6 cylinder, taken approximately perpendicular to the fracture surface. (See segment marked by tape in Fig. 8) Approx. 15X

Fig. 10: A second view of fracture surface shown in Fig. 9, taken approximately perpendicular to wire surface. Approx. 15X

DIESEL TO DETRITUS

Part B

Observation

The fracture surface of the spring (Figs. 9 & 10) is typical of a fatigue failure. The bright region in the fracture surface (Fig. 9) is relatively smooth and failed first. The typical "beach marks" of fatigue were not as well developed (or obvious) as one might like (and often sees). No doubt, electron microscopy would have made the fatigue striations clear. The bright region in Fig. 9 is the "smooth" region at the front of the fracture surface in Fig. 10.

The rough surface (pitted or pockmarked) of the spring segment shown in Figs. 9 & 10 provides ample points of stress concentration to initiate fatigue failure. Operation of the spring clearly provided cyclic stressing in the spring. It might be noted that failure started on the inside radius of the spring where the tensile stresses are much higher than on the outside radius of the spring. It might also be noted that the surface of the spring from No. 5 cylinder (Fig. 8) is slightly rough, presumably from shot peening, which is performed to introduce residual compressive stresses on the surface to develop longer service life. It is obvious that the "roughness" from shot peening is not the same as the pitting surface imperfection seen in Fig. 10.

Reconstruction of Probable Sequence

It appears that the outer inlet valve spring on No. 6 cylinder failed in fatigue. Segments of this spring then caused breakage of the deflector on the back of the intake valve head. The broken segments from the deflector fell into the combustion chamber, were beaten into No. 6 piston causing subsequent piston collapse and cylinder sleeve damage. The broken sleeve fell into the crankcase causing shearing of the crankshaft counter-weight which, in turn, caused damage to the cylinder block on either side of No. 6 cylinder and to the crankcase wall.

Comments

The outer inlet valve spring on No. 6 cylinder was not of appropriate quality and thus was defective. This can clearly be considered a manufacturing defect. It appears that this defective spring could have been detected and eliminated before assembly by better quality control. It can be argued, however, that inspection of items such as these springs would be done on a sampling basis and this spring was not one which was inspected. In this case, the manufacturer is still liable since the defective spring led to the destruction of the engine.

This case seems reminiscent of Poor Richard's maxim: "A little neglect may breed mischief: for want of a nail the shoe is lost; for want of a shoe the horse is lost; for want of a horse the rider is lost; for want of a rider the battle is lost; and for want of a battle the kingdom is lost."